Cessna Perspective on CFD for Icing Simulation

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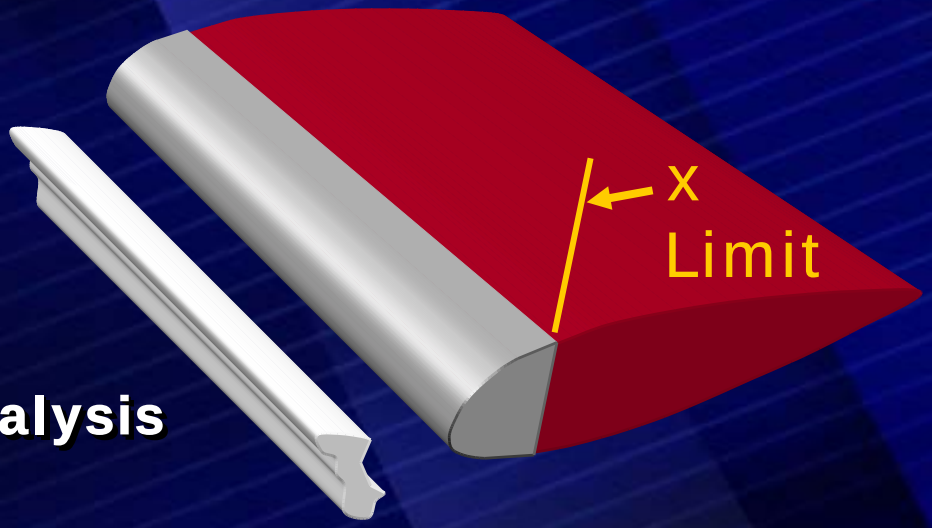
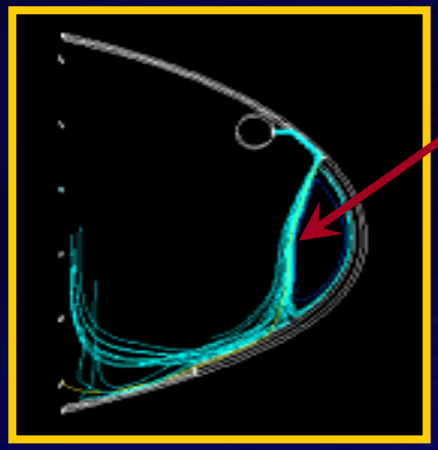
Current Use At Cessna Of CFD Tools For Icing Simulation

Overview

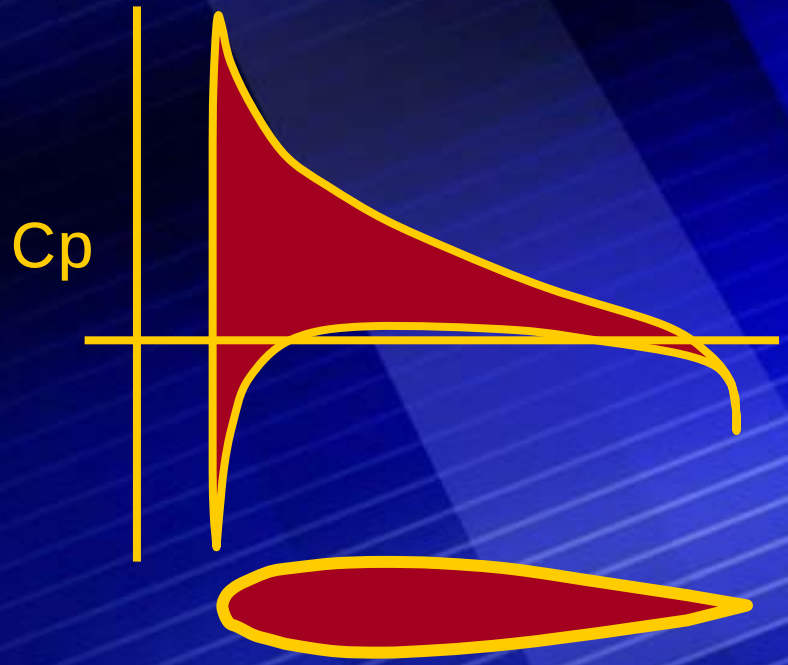
- Critical Ice Shapes
  - Aerodynamic
  - Shedding
- Impingement Limit Analysis
- Thermal Analysis
- Design Guidance





Separated flow reduces heat transfer

Landing Light Example

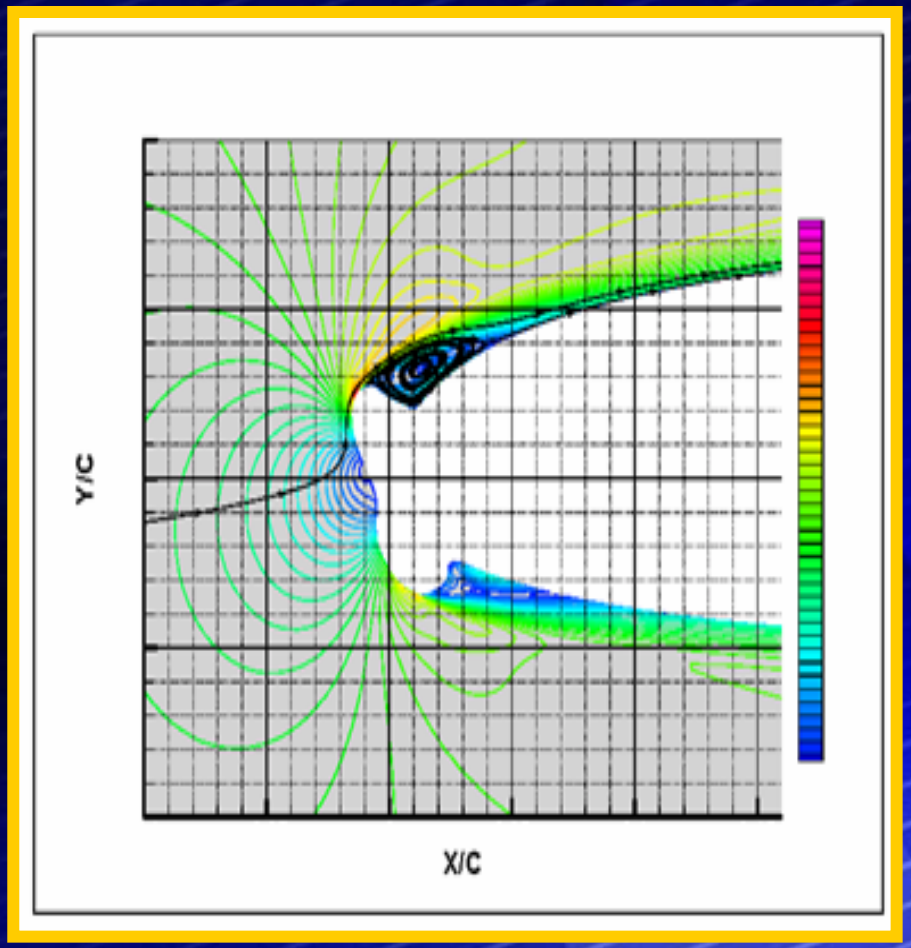


Tools

- Lewice 2D
  - Used for prediction of local collection efficiency
  - Ice shapes on areas where 2D approximations are reasonable such as wing and stabilizer leading edges
- Lewice 3D in evaluation stage
- Other CFD Codes
  - Used for prediction of local collection efficiency on areas of high 3D dependence such as windshield
  - Navier Stokes and Euler methods

Aerodynamically Critical Ice Shapes

- Ice Shape Prediction
  - By Aerodynamics group using Lewice
    - » Most experience based on v1.6
    - » Recent evaluation and switch to v3.2.2
  - Glaze and Rime ice prediction
  - Unprotected, failure, and intercycle shapes

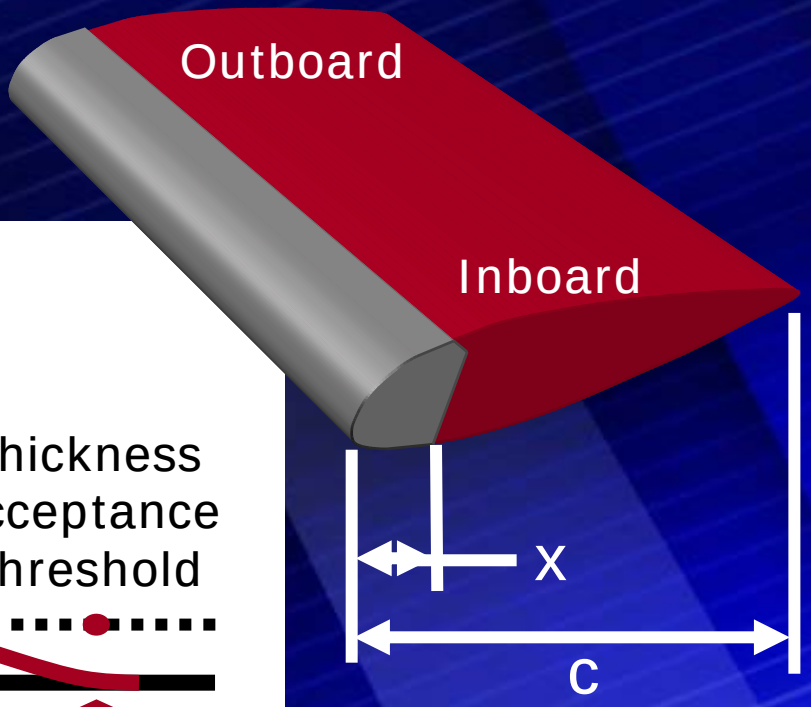


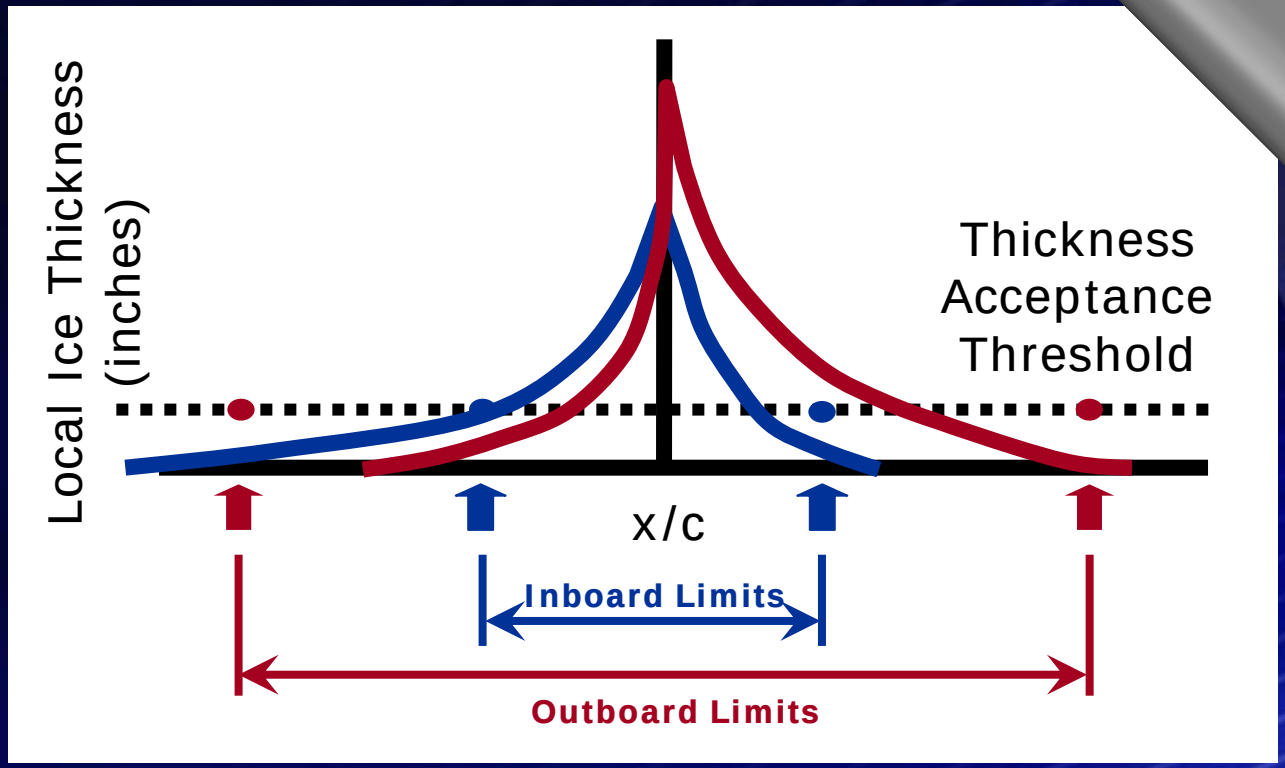
Critical Ice Shape Evaluation

- 45 minute hold condition
- Use wing tip shape as most critical location
- Glaze and rime ice conditions
- Critical temperature and droplet size
- Determination based on 2D lift loss
- Unstructured, Navier-Stokes methods
- Handling qualities effects not done with CFD

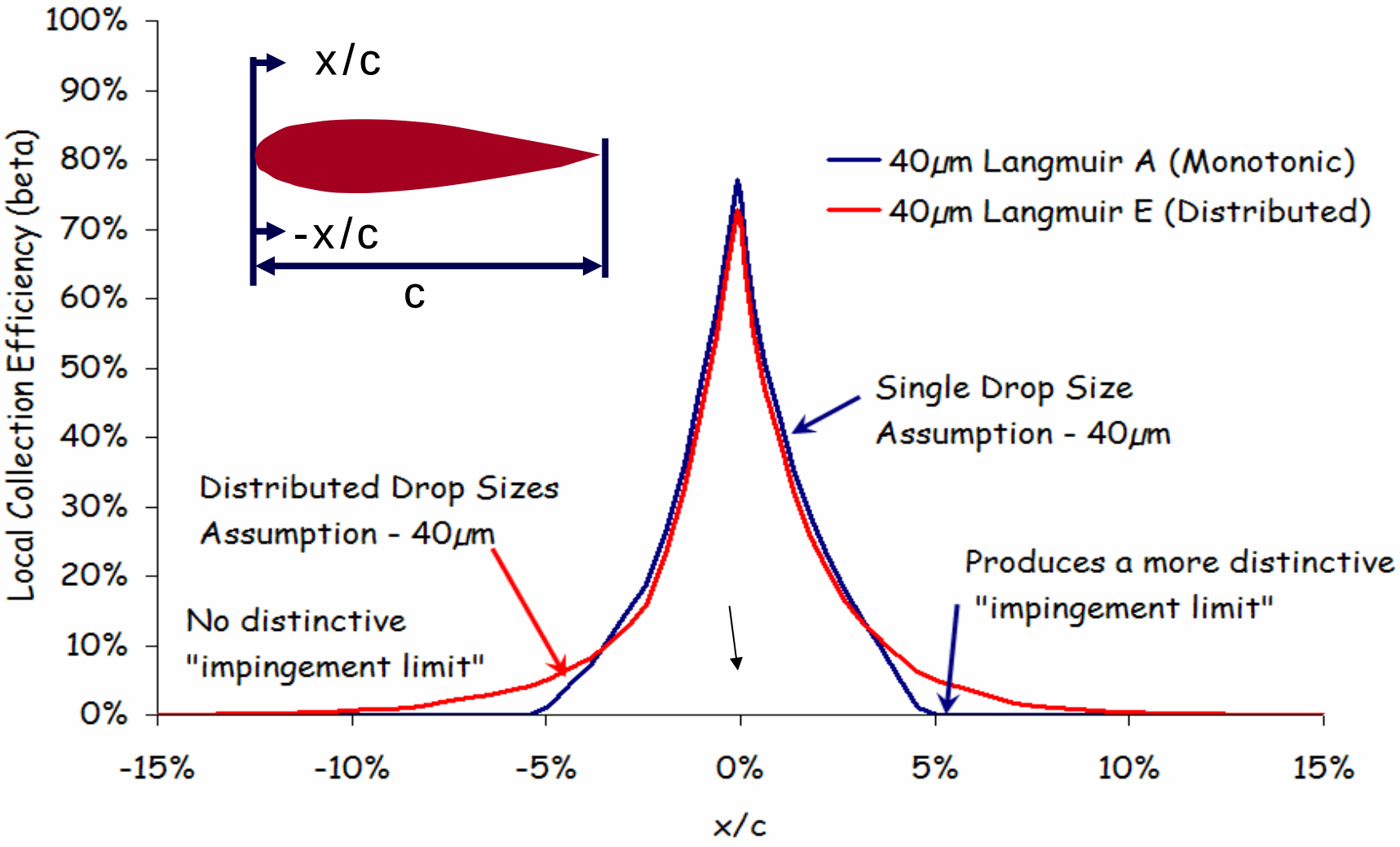
Impingement Limit Evaluation

- Recent programs used distributions per available guidance
- Requires thickness threshold to simulate roughness



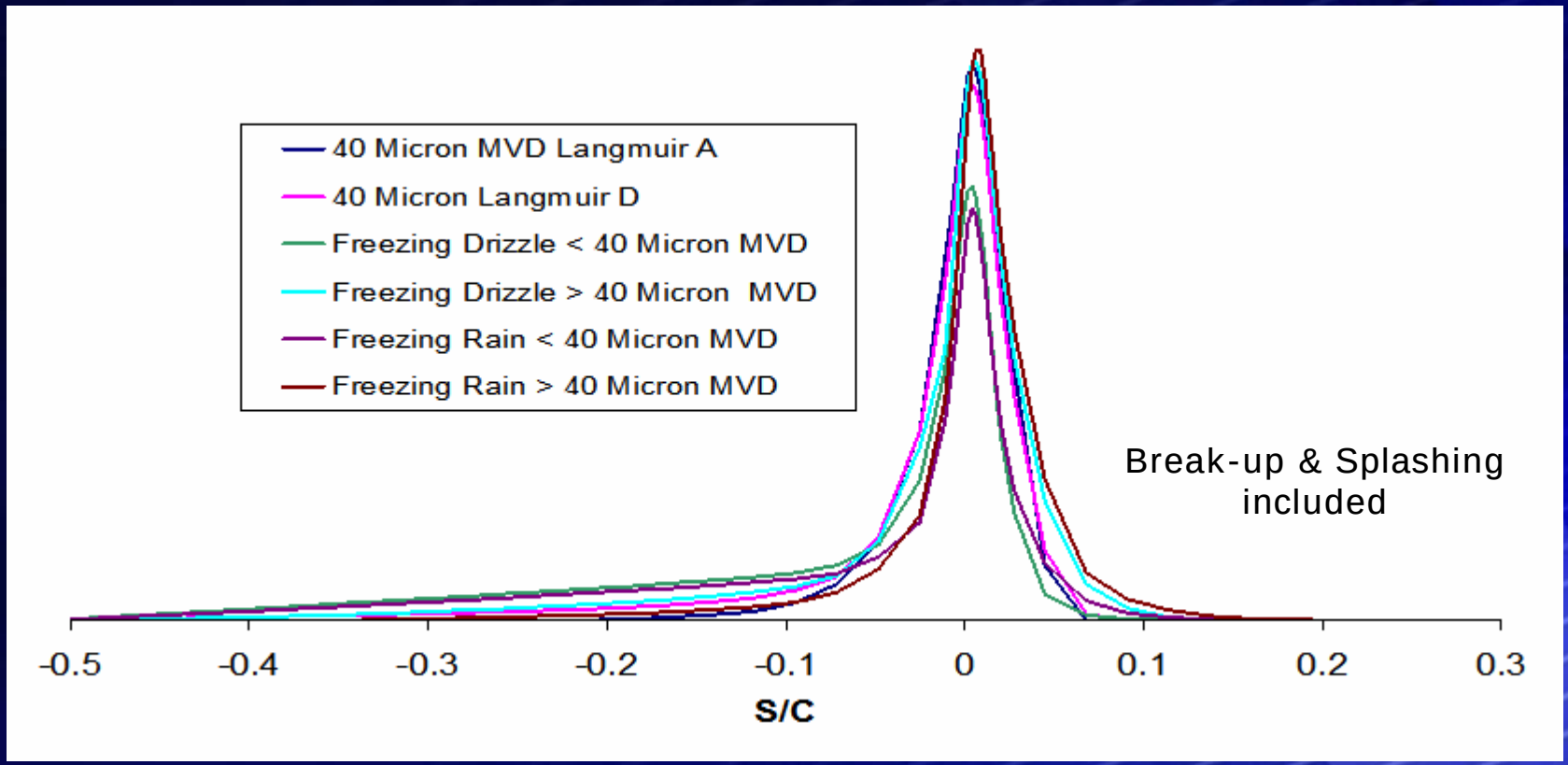


Effect of Drop Distributions



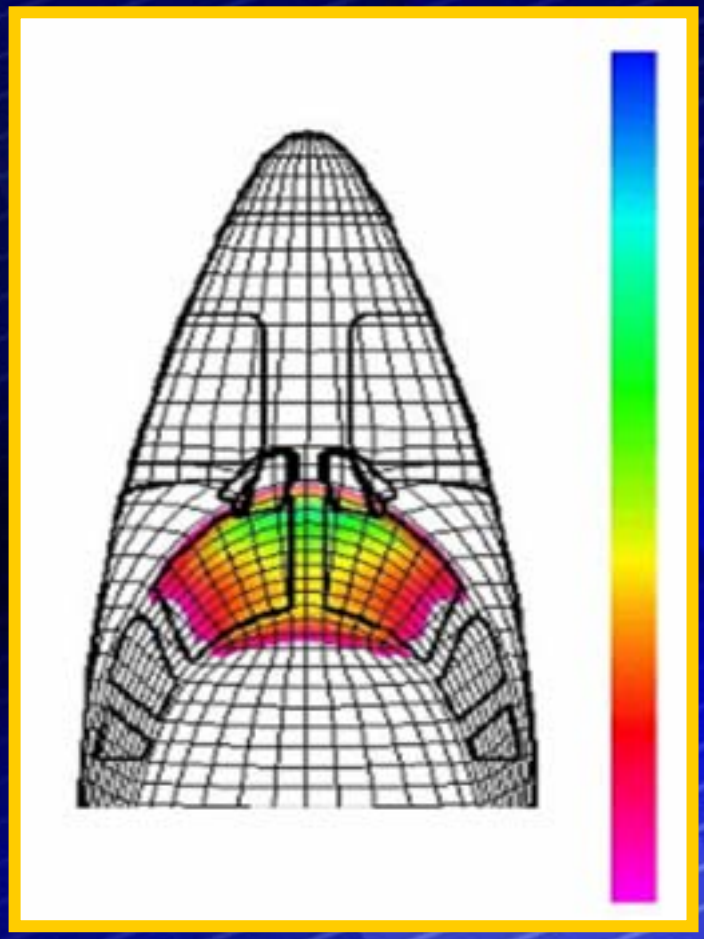
Effect of Drop Distributions (cont.)

- Effect is even more pronounced with SLD.
- "Limits" can reach 50% chord or more.



Impingement (3D)

- Windshield impingement
  - Assess heated panel requirements
  - Assess effects of system failures
- Impingement analysis w/ tanker assessment
  - Generate 3D ice shapes
  - Fairing areas

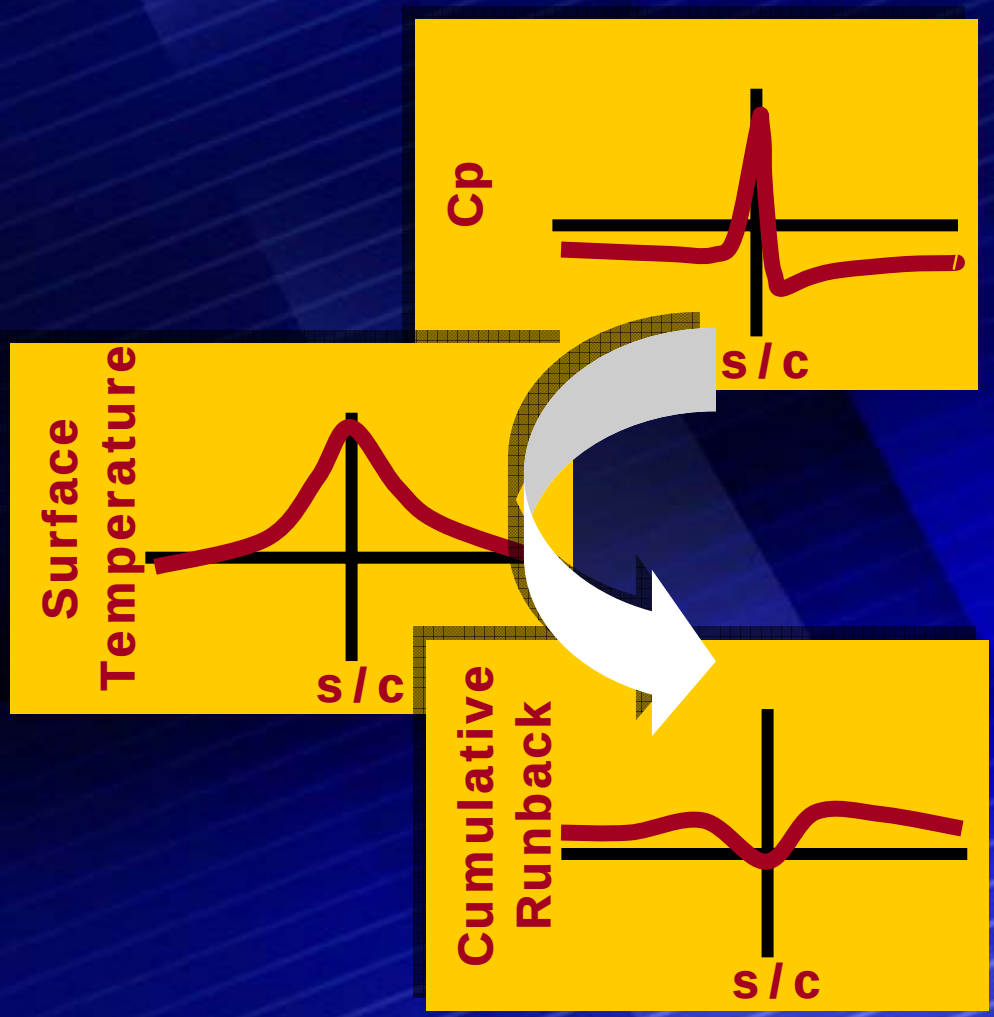


Ice Shape Development

- Ice shape generation
  - Directly from Lewice results
  - Roughness applied
- Inadvertent/Transient Encounters
  - Determine roughness limits
- Engine Ingestion
  - Thickness profiles
  - Determination of ice sizes/volumes for ground tests

Thermal Modeling

- External pressure distributions used in thermal anti-ice system models
  - To develop heat and mass transfer relationships
- Primarily 2D, but some 3D with unstructured Euler methods for pressure distributions



Supported Research on Shedding

- Supported work through ADMRC to develop ice shedding methods
  - Ice Particle Trajectory Program
- Focus was on large shapes that can damage airframe, engine
- Used Monte Carlo techniques to address random nature of initial conditions
- Developed probable trajectory maps based on variation of initial conditions
- AIAA 2006-1010, Papadakis, et.al.

ADMRC - Aircraft Design & Manufacturing Research Center

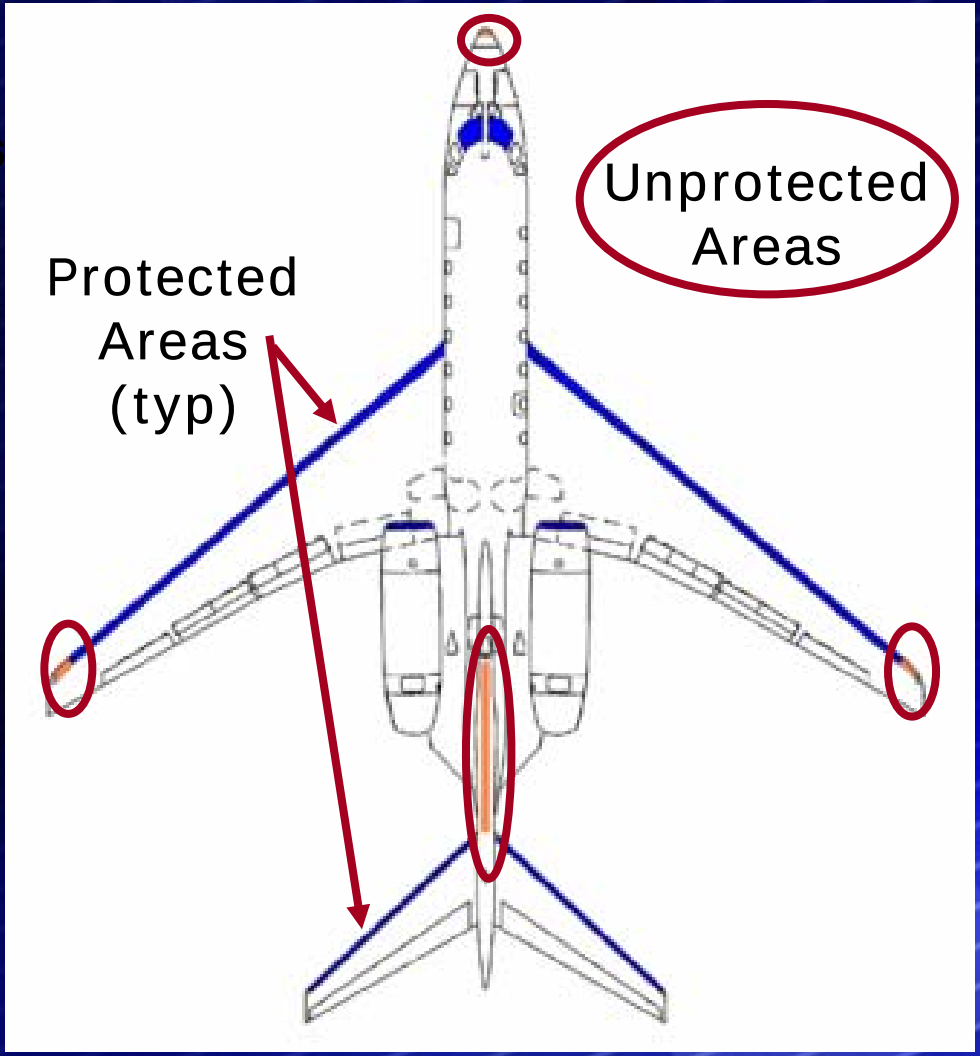
Assessment Of Readiness Of CFD Tools For SLD Simulation

Assessment of Readiness of CFD Tools for SLD Simulation

- Lewice 3.2.2 has some SLD capability
  - Splashing and breakup models
- Splashing models significantly reduce potential accretions in aft regions of leading edges
- Positive step towards modeling SLD
- Development has focused on unprotected areas
- Concerns about ability to model accretions aft of protected areas

Protected vs. Unprotected

- Large aircraft are trending towards minimal protected areas
- Scale effects limit the feasibility of this on smaller scale aircraft
- Unprotected areas have limited effect on small aircraft performance and handling qualities
  - Due to limited span of such shapes

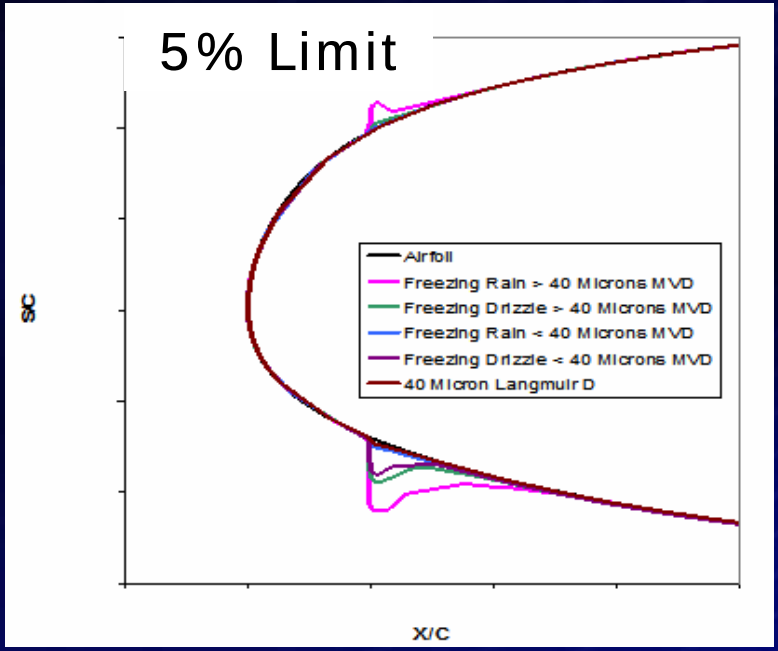


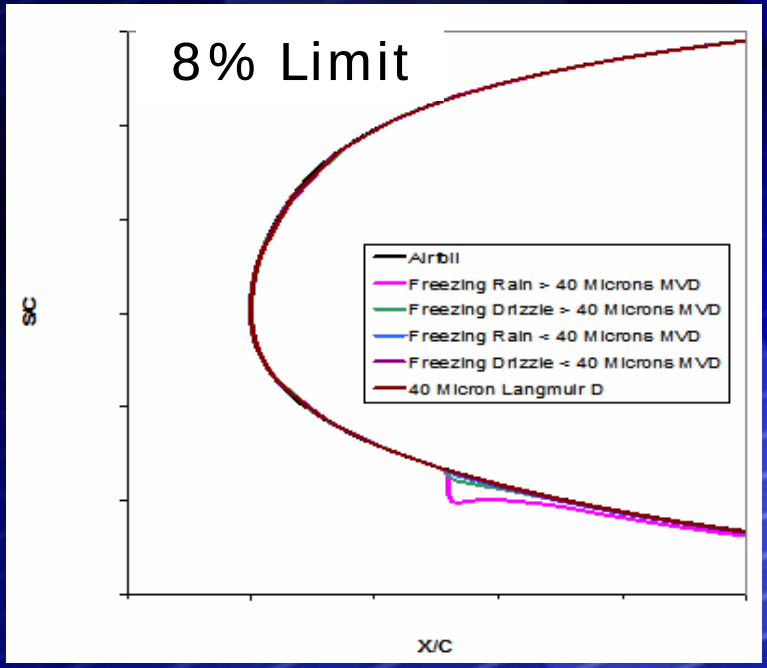
Protected Area SLD Effects

- Protected areas have a much larger influence on aircraft performance and handling qualities
  - Handling quality assessment is becoming more critical
    - » Part 23 requires "Capable of operating safely"
      - Airplane performance, controllability, maneuverability, and stability must not be less than that required in part 23, subpart B
      - Same standards as for clean aircraft
    - » Part 25 rulemaking is nearing publication
      - Some differences, but similar to Part 23 requirements
- Current methods do not support full aircraft handling quality predictions

Protected Area Shapes

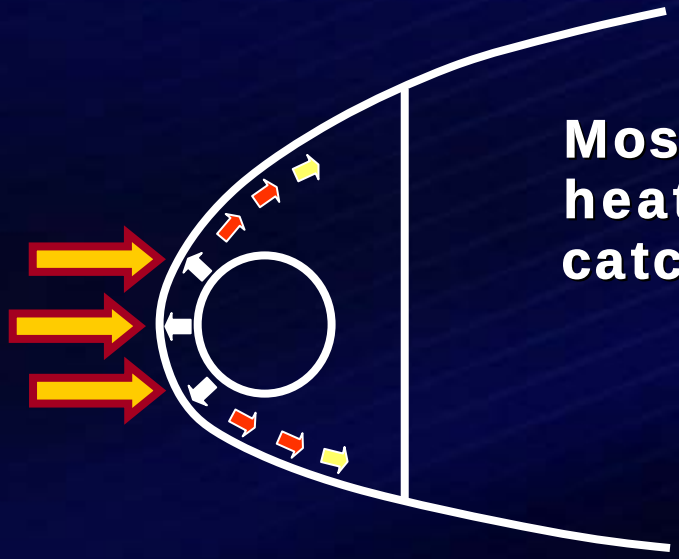
- CFD tools are currently not capable of predicting ice accumulations behind protected areas
  - Lewice has rudimentary pneumatic deicer model
  - Trend appears correct, but unvalidated





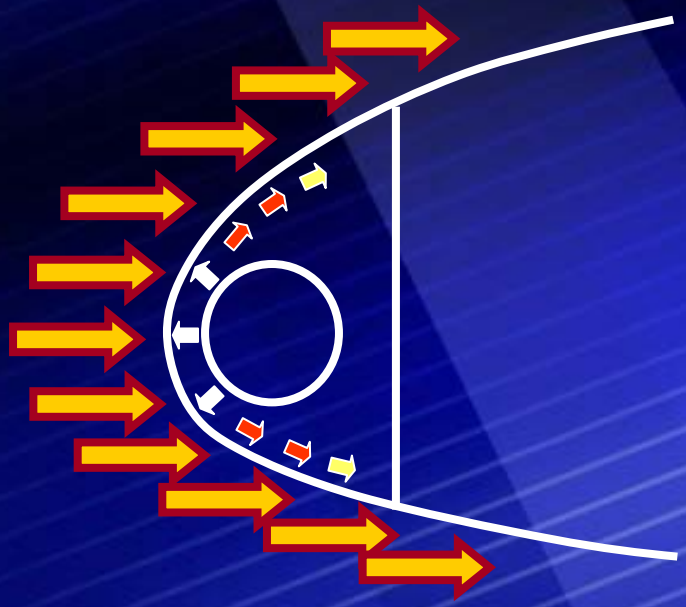
Ice Protection Example - Thermal

- No methods available to predict accumulation effects of SLD aft of thermal systems



Most thermal systems focus heat on Appendix C water catch regions

SLD promotes higher water catch in areas of reduced heat transfer promoting runback



Identification Of Strengths And Weaknesses In Current Simulation Tools

Potential Accumulations Aft of Protected Areas

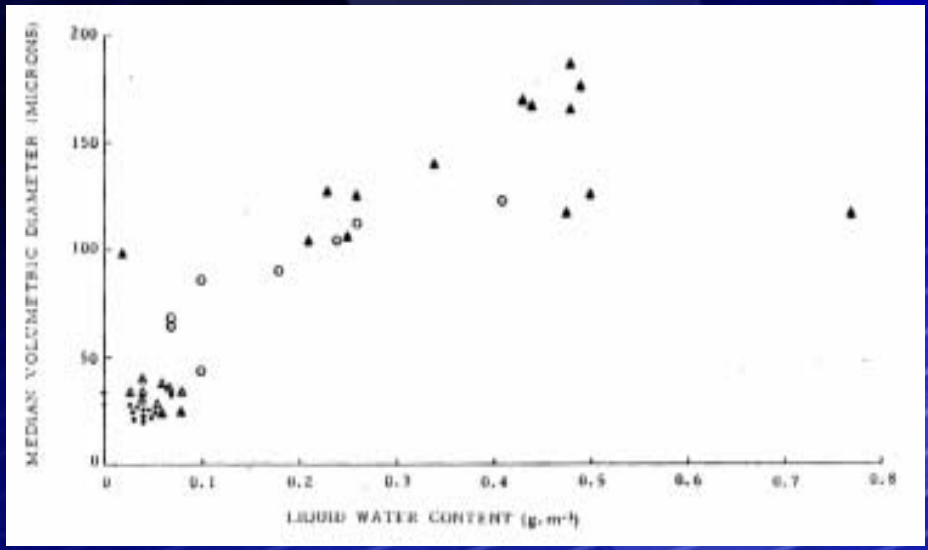
- Need CFD methods to determine ice formations aft of protected areas
  - Potential for direct impingement
- Needs to consider all potential icing systems
  - Mechanical deice
  - Thermal anti-ice and deice

Strengths and Weaknesses of Current Simulation Tools

- Current IPHWG draft AC recommends use of multiple tools
  - Intent of multiple tools was to "cross-validate" SLD effects
    - To increase confidence in results
    - Mitigates the impracticality of flight testing in natural SLD
- Current methods do not support the use of multiple tools
  - Some categories of SLD only have one valid method of assessing ice shapes

Icing Tankers

- Freezing drizzle is possible
  - Fixed drop size
- Ability to produce distributions limited
  - Multiple nozzle approach for distribution effects may not be feasible for airborne hardware
  - Excessive structure required to mount



Icing Tankers (cont.)

- No freezing rain capability
- Technical challenges appear to exist in producing freezing rain
  - Droplet breakup due to velocity differentials at nozzle is a concern
    - » Air Force tanker does "rain" testing
      - Primary focus is engine ingestion, not impingement
      - Droplet break up effects are not quantified
  - Ability to sub-cool larger drops is unknown
  - Similar constraints to drizzle on distribution effects

Icing Tunnels

- Work is on-going to produce FZDZ distribution effects in icing tunnels
  - Superimposing large and small drops
    - » May be adequate on unprotected surfaces
  - Concerns with superposition on thermal systems
    - » Heat loads / freezing fractions would fluctuate with the drop sizes
- Direct representation of freezing rain in tunnels is still an unknown
  - Sub-cooling ability; droplet break up with injection; cloud size
- Thermal scaling on protected surfaces

SLD Simulation Tool Maturity Assessment

SLD Type	CFD Methods		Icing Tunnel		Icing Tanker	
	Unprotected Surfaces	Protected Surfaces	Unprotected Surfaces	Protected Surfaces	Unprotected Surfaces	Protected Surfaces
FZDZ MVD<40μm						
FZDZ MVD>40μm						
FZRA MVD<40μm						
FZRA MVD>40μm						

Potential compliance method

May be feasible (but compliance potential is unknown)

Not feasible at the current time, no known development activity

Notes: Protected surfaces considers accretion behind both mechanical and thermal ice protection methods

Recommendations for future research in SLD simulation

Needs List

- Prediction of ice shapes behind protected areas
  - Considering thermal anti-ice and deice systems
  - Mechanical deice systems
- Aerodynamic effects of roughness and low profile ice shapes behind protected areas
  - 2D effects on C_L, C_D for assessment of critical shapes
  - Airflow separation points may not be well defined
- Ice Shedding
  - Probabilistic; Ice breakup; Focus on engine ingestion
- Full aircraft handling quality effects
  - Effects on stall characteristics
  - Stability and control

What Research Areas Should Have The Highest Priority

Priorities

1. Prediction of shapes behind protected areas
   - Considering thermal anti-ice and deice systems
   - Mechanical deice systems
2. Aerodynamic effects of roughness and low profile ice shapes, behind protected areas
   - 2D effects on C_L, C_D for assessment of critical iced shapes
   - Airflow separation points may not be well defined
3. Ice Shedding
   - Probabilistic techniques
   - Breakup

Thank You!

Questions?